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SMALL EARTHQUAKES IN THE NEVADA REGION, AND EARTHQUAKE ACTIVITY AND STRAIN CHANGES ASSOCIATED WITH UNDERGROUND EXPLOSIONS

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Summary

This report covers the status of the University of Nevada Strain program for the period June 1, 1972 to May 31, 1973. During this period the stations at Mina and Round Mountain have provided continuous secular strain data. Work on the station at Kaiserville was postponed until June, 1973, and is now near completion.

→ 10 to the -6th power

The data from the station at Mina and Round Mountain have been analyzed through May 15, 1973. These strain measurements indicate that in this area of the Basin and Range, strain rates are less than 2×10^{-6} per year. These observations are in agreement with estimated spreading rates and geodetic measurements in the Great Basin. The observations at Round Mountain and nearby focal mechanism solutions suggests that we are observing strain accumulation in this area. The long-term strain at Mina is more variable, but generally agrees with earthquake focal mechanism solutions. The strain rate, in conjunction with the high seismicity of the Mina area suggest that strain has already accumulated, and is presently being released through inelastic processes. Changes in strain rate around the time of an earthquake swarm near Mina in May, 1972 may represent a premonitory effect of the type proposed by Scholz and others.

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The data from the station at Mina and Round Mountain have been analyzed through May 15, 1973. These strain measurements indicate that in this area of the Basin and Range, strain rates are less than 2×10^{-6} per year. These observations are in agreement with estimated spreading rates and geodetic measurements in the Great Basin. The observations at Round Mountain and nearby focal mechanism solutions suggests that we are observing strain accumulation in this area. The long-term strain at Mina is more variable, but generally agrees with earthquake focal mechanism solutions. The strain rate, in conjunction with the high

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seismicity of the Mina area suggest that strain has already accumulated, and is presently being released through inelastic processes. Changes in strain rate around the time of an earthquake swarm near Mina in May, 1972 may represent a premonitory effect of the type proposed by Scholz and others.

STATUS OF THE UNIVERSITY OF NEVADA STRAIN PROGRAM

1 June 1972 - 31 May 1973

by

Keith Priestley

Introduction

Since April 1969, the University of Nevada Seismological Laboratory has committed a major part of its research effort to an investigation of crustal strain in the Nevada region. Three-component strain stations were constructed in mines at Round Mountain and Mina, Nevada (Figure 1). A third station is near completion in a mine at Kaiserville, Nevada, which lies within the aftershock zone of the 1954 Fairview Peak earthquake.

THE ROUND MOUNTAIN STATION

The Round Mountain station is located in a mine, 400 feet below the surface, in an aseismic area of central Nevada. Equipment at this station, and at Mina, consists of 80-foot long quartz-tube strainmeters, patterned after instruments built previously by the Colorado School of Mines. Work on the site was begun in the Summer of 1969, and the station began continuous operation in January 1970. During the summer and fall of 1971, the oscillators gradually deteriorated due to moisture, and the sensitivity of the strainmeters dropped - to zero for the 108.0° component and by a factor of about ten for the 167.0° component and 35.0° component. In March, 1972, the oscillators were repaired and watertight boxes were installed to protect the transducers and oscillators from future damage by moisture. However, the station was again out of continuous operation for about two and one half months in the Fall of 1972 when the power lines to the site were damaged in a storm. There were calibrations near both the beginning and ending of this period so that no secular strain data was lost.

Considerable difficulty has been encountered with the Hewlett-Packard 7127A recorders used at Round Mountain and Mina. As supplied from the manufacturer, the chart drive transmission contains plastic gears which are inadequate for the continuous operation we require. These gears have been replaced with brass gears and we expect no more trouble from this point. However, there is still a problem with the paper take-up system, and the Hewlett-Packard engineering office is presently trying to correct this problem.

THE MINA STATION

The Mina station is located in a mine tunnel driven 700 feet horizontally into a mountainside in the Garfield Hills, one of the most active seismic areas in Nevada. One component of this installation was operated briefly at the time of the Handley explosion, 26 March 1970, but the station did not begin full-scale operation until January, 1971. During the summer of 1971 the instruments were damaged, by water and unskilled operators, and in August the transducers were brought back to Reno for overhaul. On 25 January 1972 the instrumentation was reassembled; however, difficulties with the power system developed which were not

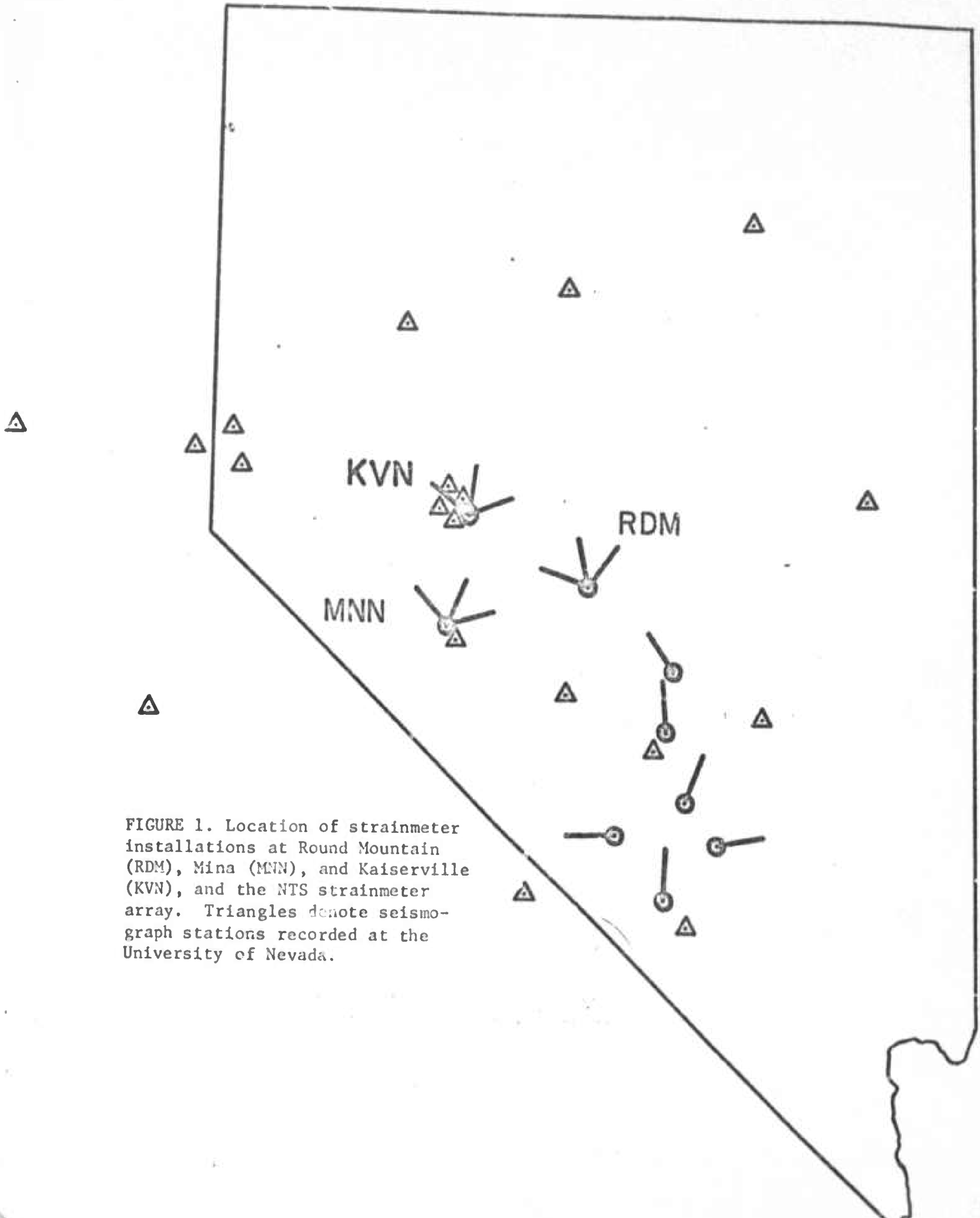

FIGURE 1. Location of strainmeter installations at Round Mountain (RDM), Mina (MNN), and Kaiserville (KVN), and the NTS strainmeter array. Triangles denote seismograph stations recorded at the University of Nevada.

corrected until 31 March, when new cables were installed in the tunnel. On April 15, water-tight boxes were installed to protect the transducers and oscillators. Except for mechanical difficulties with the Hewlett-Packard chart recorders, all three components have been operational since that time.

THE KAISERVILLE STATION

The Kaiserville station is located 700 feet below the surface, in a mine located directly above the focal zone of the aftershocks of the 1954 Fairview Peak earthquake. Work at Kaiserville began in June, 1972, and during the summer of 1972 the instrument drifts were cleared, piers were constructed, thermal walls built, and the transducers and quartz were installed. However, further work was postponed when a dispute over the ownership of the mine arose. This problem was settled in the Spring of 1973 and since that time, construction on the 700-foot level has been completed, and the recording room on the 100-foot level has been completed. The recording system has been checked out, the electronics have been checked out and repackaged, and a power system has been installed at the mine, using thermo-electric generators. The electronics will be installed within the next month, and the installation should become operational at that time.

ANALYSIS AND RESULTS

Quality of Data. It is important to establish the quality of the strainmeter site, before the resulting data can be used for geophysical research. Figure 2 is a comparison of the observed and theoretical strain tides, in both the time and frequency domains, for all components at Round Mountain and Mina (Malone, 1972; Priestley, 1974). As pointed out by Smith and Kind (1972a), a direct comparison between observed and calculated tidal strains is an indication of the quality of coupling of the strainmeter to the earth. It also gives some measure of the effects of local inhomogeneities near the site which may distort the tidal strain field. Both the amplitude and phase of the observed tide shown in figure 2a, agrees quite well with that of the calculated tide, indicating that the strainmeters are well coupled to the earth.

Figure 2b is a comparison of spectra of observed and theoretical tides. It is important to examine the relationship between the observed and theoretical tides near 12-hour period because the S_2 (12.00 hour period) tide will contain the effects of the thermal and atmospheric tides, while the M_2 (12.42 hour period) tide will be free of such effects. Poor correspondence between the observed and theoretical tides near 12 hours may indicate poor site conditions as would be expected if the site was affected by daily temperature variations. The agreement between the relative amplitude of M_2 and S_2 for the observed and theoretical tides is quite good, indicating that neither site is affected by such environmental changes.

It is much more difficult to evaluate the long-term thermal stability of strainmeter installations. Figure 3 (Priestley, 1974) is a comparison of the observed strain at Round Mountain and Mina, and observed strain at the NTS strainmeter away from Smith and Kind (1972b). The strain variations observed at the NTS array are in general one to two orders of magnitude greater than those observed at Round Mountain and Mina. To explain this discrepency we note that all of the NTS instruments are located either in trenches, or in shallow mines, and could therefore be subjected to environmental effects. The last curve of figure 3 is

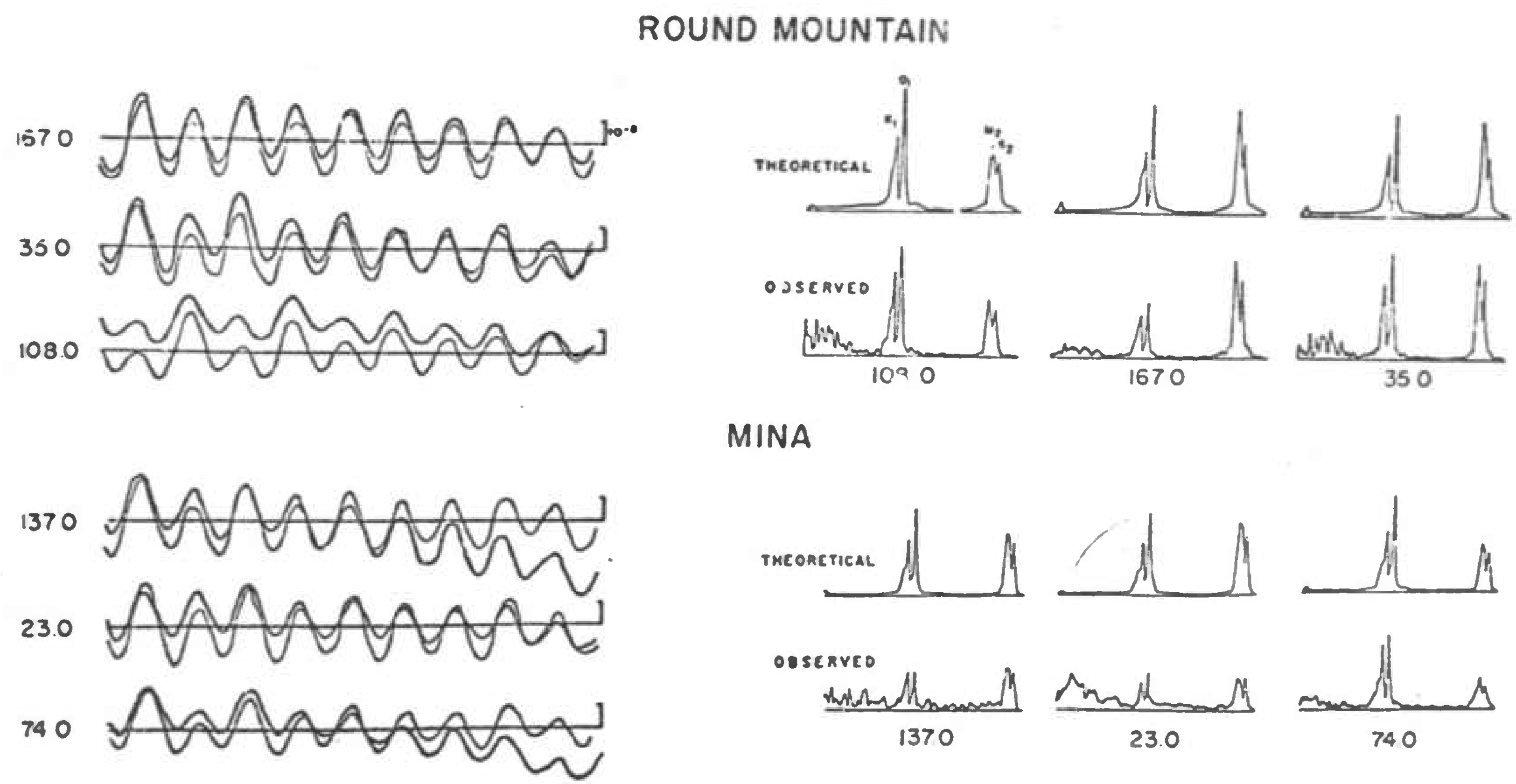

FIGURE 2. (a) Time domain relationship of the observed and calculated solid earth strain tide; (b) Frequency domain relationship of the observed and calculated solid earth strain tide.

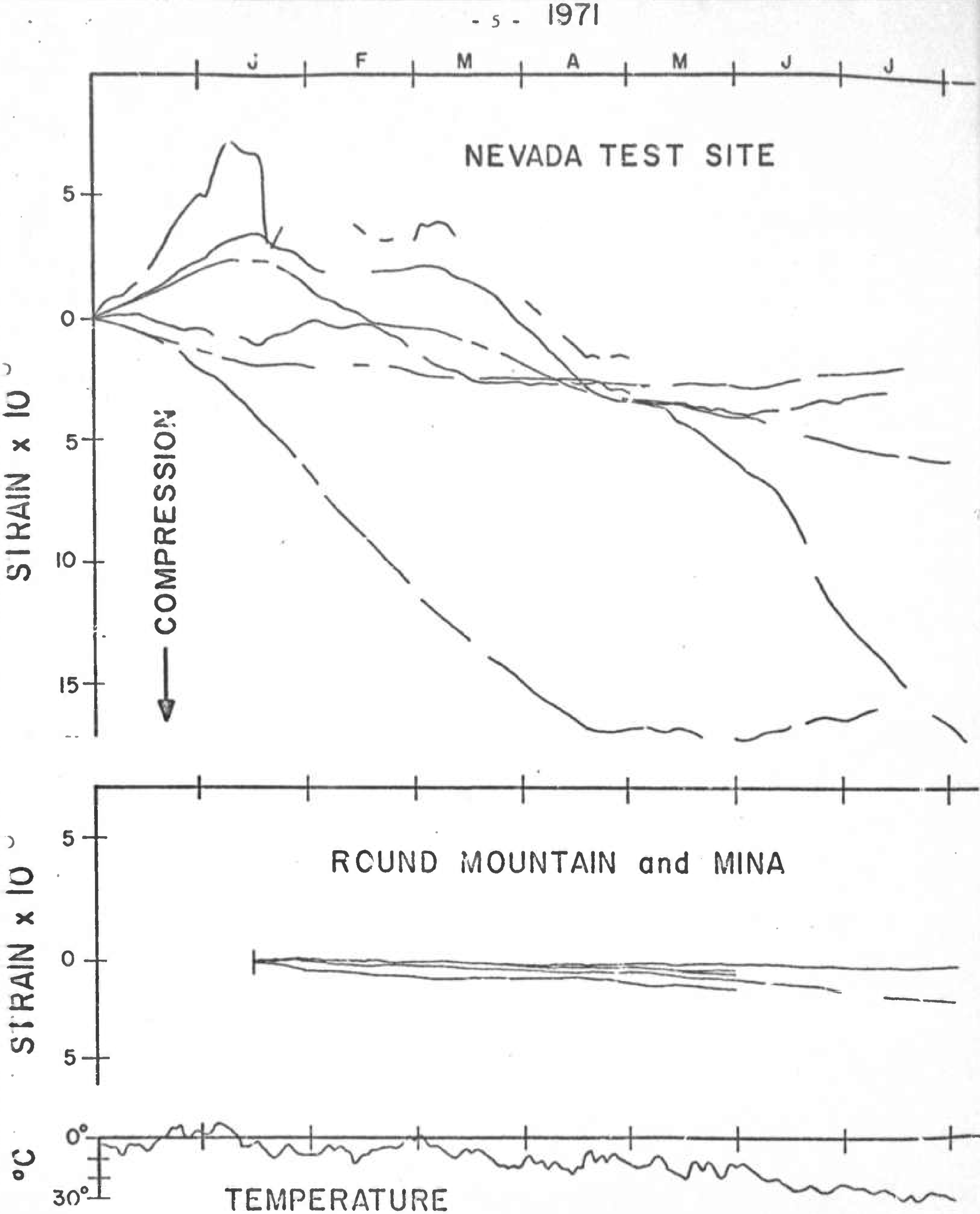

FIGURE 3. Strains observed at NTS strainmeter array, Round Mountain and Mina, compared with air temperature.

the air temperature variation at a weather station near the NTS array. This shows a long-term trend of rising temperature which seems to correlate with the generally compressive strain observed, suggesting that the NTS array sites may have been influenced by seasonal temperature variations to a much greater extent than Round Mountain or Mina. This indicates that trenches or shallow mines may not be adequate sites for strainmeters.

Tidal Strains and Tidal Triggering of Earthquakes. In Malone's (1972) investigation, a theoretical tides program was used to compare the observed and theoretical tides. Values for the Love numbers h and l were determined for the Round Mountain Station, and removal of nontidal strains due to barometric and temperature fluctuations allowed for the exact comparison of the calculated and observed tidal strains. We are presently using the tidal strain data from Round Mountain and Mina to investigate the tidal phase lag.

Secular Strain. Long-term strain changes at Round Mountain for the period from March 1970 to May 1971, and at Mina for the first third of 1971, were interpreted by Malone (1972) in terms of a buildup in compressive strain, with an average strain rate at Round Mountain of about $4x10^{-6}$ per year. More recent data indicates that these initial observations resulted from a gradual warming in the mine after thermal bulkheads were installed and the air circulation was cut off. Figure 4 indicates that the strain rates are probably less than $2x10^{-6}$ per year (Priestley, 1974). These strain rates are consistent with geodetic measurements (Savage, et al., 1973) in the region, and with spreading rates estimated from the geology and geometry of the western Great Basin (Thompson and Burke, 1973).

Figure 5 compares the observed strain field at Round Mountain and Mina, indicated by strain ellipses, with focal mechanisms of earthquakes in the Nevada Region. The strain pattern at Round Mountain is in general agreement with focal mechanisms for nearby earthquakes suggesting that we are observing strain accumulation. Slight differences can probably be attributed to local effects. Although the strain at Mina is much more variable, the strain pattern for the whole period of observation is in agreement with focal mechanisms for earthquakes in the Mina area. It appears that the principal axes of strain in the Mina area are fairly stable in time, but change sense. During the first part of the period of observation, the axis of compression was oriented northwest-southeast. This later reversed and became the axis of extension.

The difference in the strain rate at Mina and Round Mountain was initially puzzling, considering the difference in seismic activity. Since the Mina area is seismically much more active than the Round Mountain area, one would guess that the strain rate at Mina would be greater than the strain rate at Round Mountain.

In a recent review of laboratory work on micro-fracturing of rock, Scholz (1970) proposed four stages of deformation for a rock sample under compression and these are shown in Figure 6. Initially (Stage I) the sample decreases in volume at a rate greater than expected from elastic theory, and there is a nominal level of microfracturing. Both of these are interpreted as the result of the closing of pre-existing cracks and pores by the applied stress. Stage II is characterized by a linear strain rate, which agrees with the Young's modular and compressibility of the sample measured in other ways, and by an absence of microfracturing. Deformation in this stage is considered to be nearly linearly elastic. In Stage III, dilatancy occurs and the rate of microfracturing increases. Both of these effects are thought to be associated with the opening of new cracks.

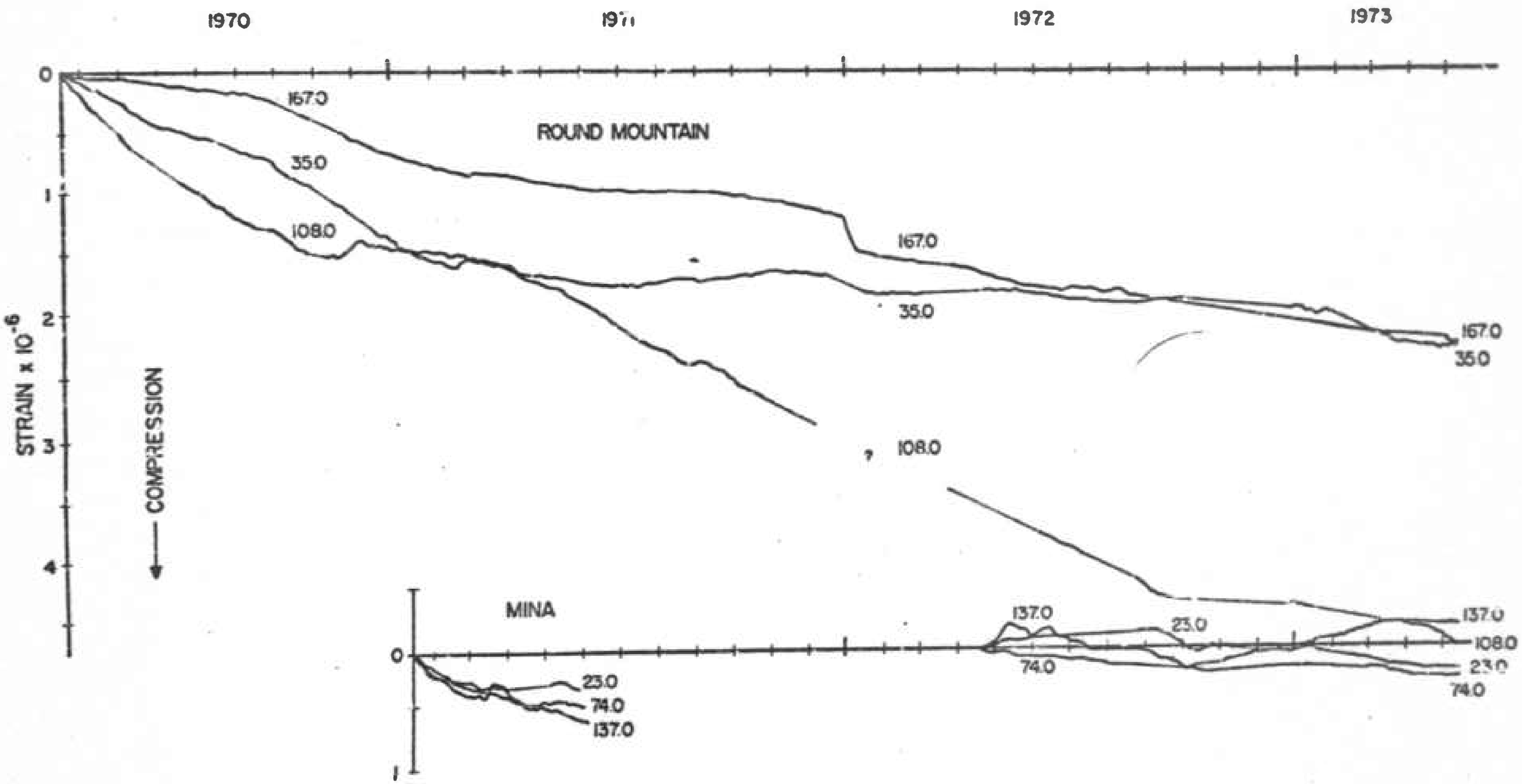

FIGURE 4. Observed long-term strain at Round Mountain and Mina. Dotted lines denote times when the instruments were not recording continuously.

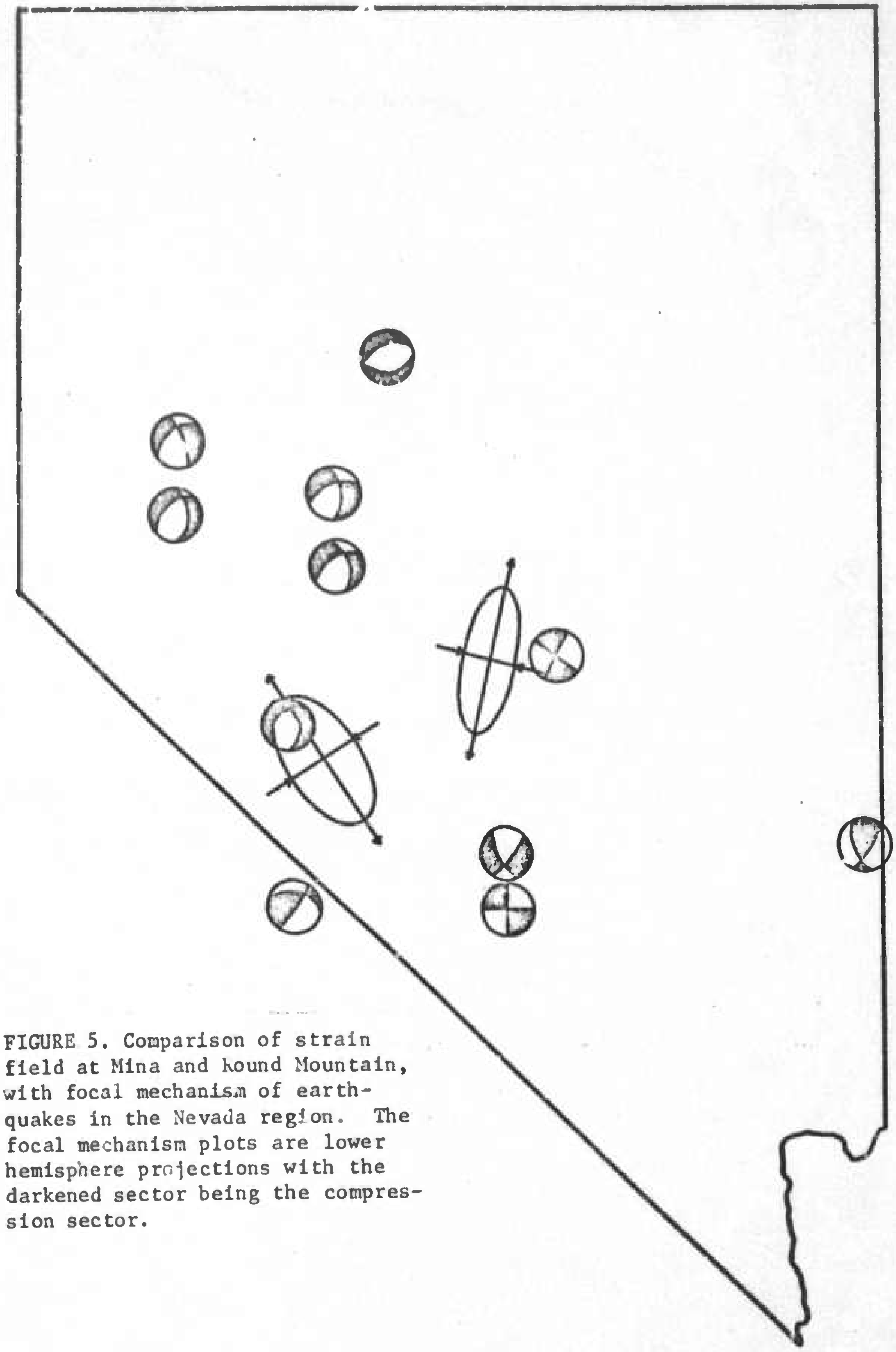

FIGURE 5. Comparison of strain field at Mina and Round Mountain, with focal mechanism of earthquakes in the Nevada region. The focal mechanism plots are lower hemisphere projections with the darkened sector being the compression sector.

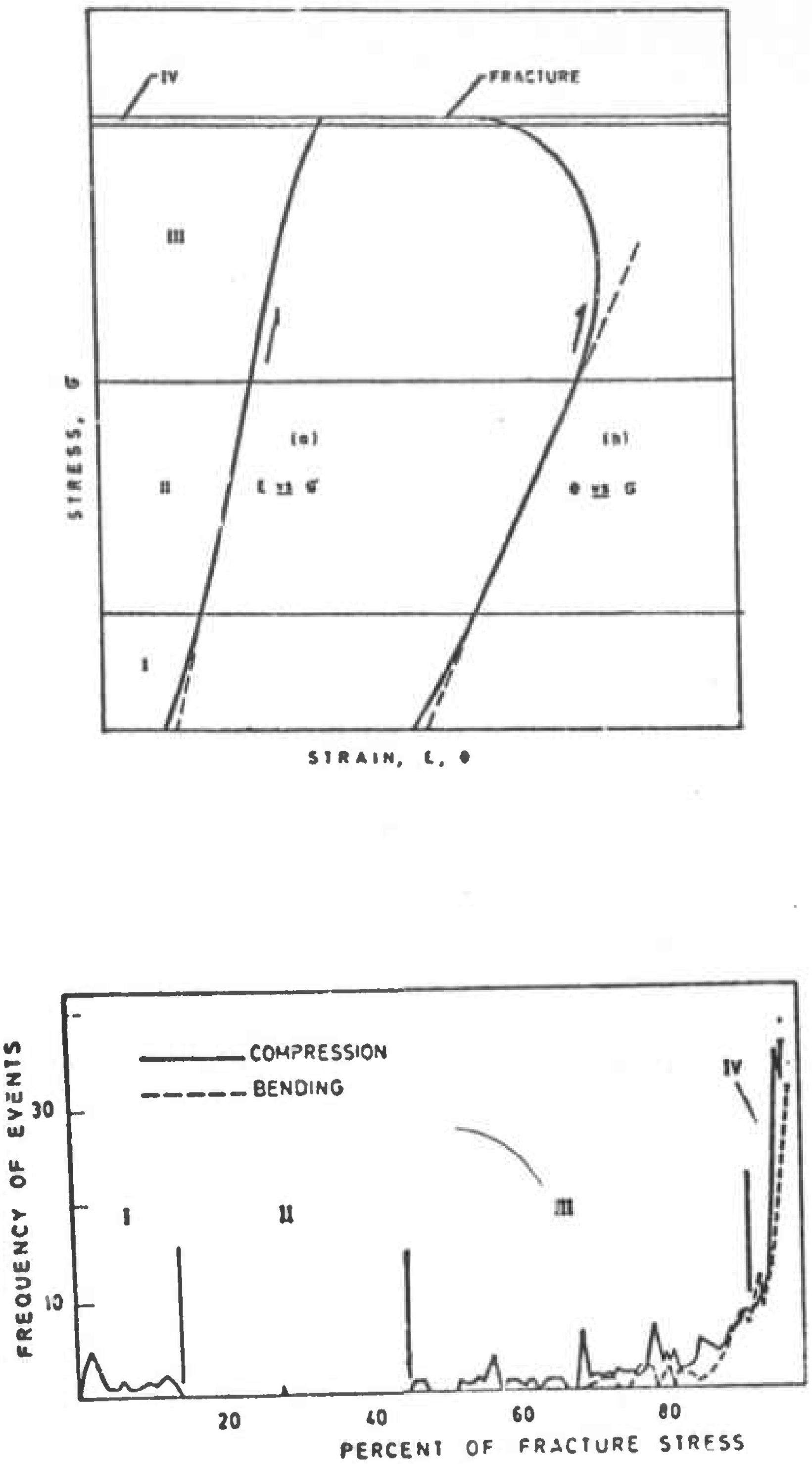

FIGURE 6. (a) Stages of deformation for a rock sample under compression; (b) Rate of microfracturing in rock samples under deformation (from Scholz, 1970).

The last stage (Stage IV) is characterized by greatly increased dilatancy, and a high level of micr fracture, prior to the main rupture.

Such results cannot be directly applied to the rocks of the Great Basin, which are undergoing extension. However, we can visualize stages equivalent to Stages II, III, and IV. The higher strain rates, and low seismic activity of the Round Mountain area suggest that this area may be in the equivalent of Stage II, where the deformation is nearly linear elastic. The lower and variable strain rates, and higher level of seismic activity of the Mina area suggest that this area may be in the equivalent of Stage III or Stage IV, where deformation is taking place by inelastic processes. It is interesting to note that in a study of seismic potential of the western Great Basin, Ryall, and others interpreted the high seismicity in the Mina area as an indication of high potential for a moderate to large earthquake there in the near future, i.e. Stages III or IV.

Strain Offsets. Static strains related to large seismic events have been observed at both the Round Mountain and Mina stations during nuclear explosions and natural earthquakes (Boucher, et al., 1971; Malone, 1972). Strain steps observed for nuclear explosions Handley and Jorum were appropriate for the event size and shot-receiver distances, based on the $R^{-3/2}$ amplitude dependence of Wideman and Major (1967). At the time of the San Fernando earthquake, the largest reliable offsets at Round Mountain and Mina were 1.4×10^{-9} and 1.8×10^{-9}, respectively, which were about half the amplitude predicted by the Wideman and Major relationship. During the period prior to May, 1971, the largest natural seismic event in Nevada was a magnitude 4-1/2 earthquake, which occurred at some distance from both strain stations and did not produce a detectable strain offset. Since that time, all of our records have been searched for offsets at the times of regional events, but none has been identified. Since May, 1971, the largest event in Nevada had magnitude 3.7, and at a distance of about 90 km from Round Mountain would have been expected to produce a strain step of only 5×10^{-10}, which would not have been detected on the records.

Strain Observations Associated with Seismic Activity. According to Reid's elastic rebound theory of earthquakes, earthquakes are the result of a sudden release of shear stress, which has built up over a long period of time prior to the earthquake. If this theory is valid, then substantial elastic strain occurs in the focal region before an earthquake. The peak values of elastic strain are likely to be of order 10^{-4}, but this may be apparent only very locally and immediately before an earthquake. Under favorable conditions, it should be possible to observe this buildup of strain, prior to the resulting earthquake.

Figure 7 (Priestley, 1973a,b) compares the local seismicity at Mina, with the strain rate. Here local earthquakes are considered to be those with a S-P at Mina of 6 seconds or less. Few of these events were large enough to be located, as most only recorded at Mina. This comparison indicates that there are strain changes during periods of increased seismic activity, but in some cases there may be changes which take place with no associated activity. The peak in seismic activity on May 30 corresponds to a swarm of more than 20 small events located about 15 kilometers northwest of the strainmeter site. There is a change in strain rate on all components near this time. From the shape of the strain curves, and the changes in the rate of events, there is a suggestion that this may represent a premonitory effect such as proposed by Scholz. As the seismicity or rate of events decreases, the area undergoes a volumetric increase due to dilatancy. This is then relived during the main event, or in this case, by a swarm of events. More work will have to be done before anything conclusive can be said about this.

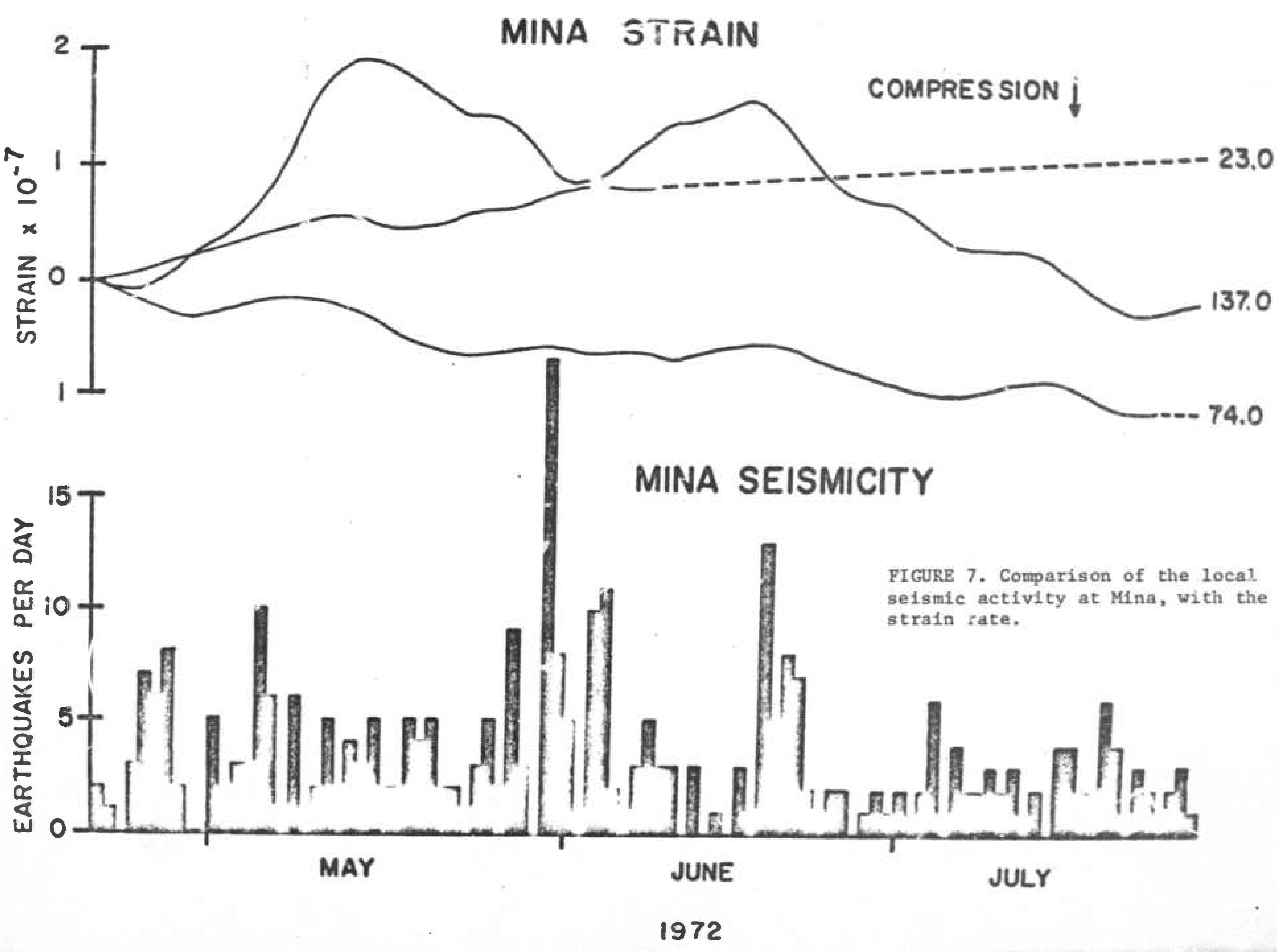

FIGURE 7. Comparison of the local seismic activity at Mina, with the strain rate.

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